COSMOCHEMISTRY IN THE EARLY UNIVERSE

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Abstract. [1] At early times the Universe was filled up with an extremely dense and hot gas. Due to the expansion it cooled below the binding energies of atoms which led to the formation of the first nuclei. In the physical environment of the post-recombination period of hydrogen, molecules such as H_2, HD and LiH can be formed. The proto-object formation, resulting from the growth of linear density fluctuations in the early Universe, can have an important impact on the chemical state of the Universe. Hence it can be enriched with metals, and thus lead to the formation of the first pre-biotic molecules.
In this contribution, I will present some scheme for the formation of primordial molecules and discuss the consequence of the formation of first stars on the existence of possible primordial pre-biotic.

1. Introduction

The conventional model of nucleosynthesis is the process by which chemical elements and their isotopes are formed, the heavy elements (carbon, oxygen, nitrogen and heavier ones) are thought to be the result of thermonuclear burning in stars, and especially the relatively rare stars which become supernovae [1], [2].
Standard big bang nucleosynthesis generated just a few elements: hydrogen, deuterium, helium and lithium, traces of beryllium and boron. The recombi-

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nation of this primeval plasma led progressively to form the neutral species at $\sim 10^9$ yr after the big bang. Little is known about the history of the Universe corresponding to 10^6-10^9 years (or to redshifts of $z \sim 1000 - 5$) after the big bang, and only recently astrophysicists begun to investigate seriously the post-recombination era and particularly the problem of the formation of the first molecules [3], [4], [5].
It is usually supposed that the first objects (first stars or galaxies) could be formed from a gas cloud by the gravitational attraction. The clouds contract adiabatically and some kind of *cryogen* is necessary to form bound systems. Since the primeval gas does not contain heavy elements like carbon, primordial molecules such as H_2, HD and LiH are good candidates to lead to an efficient cooling [6], [7]. In this context primordial molecules can play an important role in the pregalactic gas particularly on the thermochemical stability [8], [9].
In this contribution, I will present in Sect. 2 the formation of primordial molecules. Then in Sect. 3, I will describe how these molecules can influence on the formation of the first objects. In this context, I will discuss the important influence of these proto-objects on the second generation of molecular formation, which will be important for the formation of biomolecules. I will describe, in Sect. 4, some possible outlooks of this study.

2. Formation of primordial molecules

At the end of the recombination period of hydrogen, the ions became progressively neutralized in the order of their ionization potentials. With the creation of neutral species, molecular ions can initiate the molecular formation. The chemistry of the early Universe is the chemistry of the elements hydrogen and its isotope deuterium, helium, lithium and its isotopic forms. The ongoing physical reactions are immense after the recombination of hydrogen, the main processes are collisional (ionization, radiative recombination, attachement...) and radiative due to the presence of the cosmic microwave background radiation (photoionization, photodissociation, photodetachement) [4], [5].
Two main routes lead to H_2:

$$H^- + H \longrightarrow H_2 + e^- \quad \text{and} \quad H_2^+ + H \longrightarrow H_2 + H^+, \tag{1}$$

when HD is formed through H_2 [10] and LiH from LiH^+ [11]

$$H_2 + D^+ \longrightarrow HD + H^+ \ , \quad LiH^+ + H \longrightarrow LiH + H^+. \tag{2}$$

The reaction rates depend on the temperature. Thus the temperature and density evolution equations must be solved simultaneously, which needs in turn the simultaneous determination of molecular cooling and heating

rates [4], [5]. From the initial abundances given by the standard big bang nucleosynthesis [12], the integration of the chemical network lead to the following abundances of the main molecules at $z \sim 5$:

e^-/H	H_2/H	HD/H	LiH/H
$\sim 3 \times 10^{-4}$	$\sim 10^{-6}$	1.2×10^{-9}	$\sim 7 \times 10^{-20}$

3. First stars and cosmochemistry

The first objects formed after the molecular formation had no metals heavier than lithium. The role of molecular cooling in the fragmentation of primordial gas clouds is important [13]. The excitation of the rotational levels of H_2 and HD induce a cooling which can trigger thermal instability in the collapsing cloud [6], [9]. Thus, primordial molecules play a crucial role on the evolution of the first objects, through the process of fragmentation. The first objects can be, in some cases, massive stars [14].
Thus, as soon as stellar processes occur, proto-objects can lead through SN explosions to the formation of other molecules species, such as CO, CI or HCN. They in turn are important sources of contamination of the medium, and thus can offer different ways of early pre-biotic molecular formation. Chakrabarti showed that a significant amount of adenine, a DNA base, may be produced during molecular cloud collapse [15], through the chain reaction (HCN addition):

$$HCN + HCN \longrightarrow ... + HCN... \longrightarrow H_5C_5N_5 \text{ (adenine)}. \qquad (3)$$

Actually, the direct detection of the prebiotic molecules is not easy. For example, the tentative of detection of glycine were negative or below the confusion limit [16].

4. Outlooks

We have seen that through the formation and the evolution of the first objects, it is useful to consider DNA bases that have been produced at an early stage of the Universe. A large lepton asymmetry in the standard big bang nucleosynthesis could lead to the formation of a non-negligible number of heavier elements [17], and thus a strong incidence on the cosmochemistry. For example, the existence of primordial carbon or nitrogen can produce primordial bio-molecules or pre-biotic molecules such as amino acids, sugars, adenine just after the cosmological recombination period.
Thus, the formation of DNA bases could happen in the early history of the

Universe. Barrow pointed out the link between the biochemical timescales for the evolution of life and the astrophysical timescales that determine the time required to create an environment supported by a stable hydrogen burning star [18]. In the context of pre-biotic molecular formation in the early Universe, it is not necessary to establish this natural link between the stars and the prebiotic chemistry. Pre-biotic molecules could have contamined the first objects and planets from the beginning. Nevertheless these molecules could have been destroyed during the formation of planetary disks. Comets carrying away these molecules are thus interesting sites of protection and potential sources of contamination for planetary systems. Thus, life bases could be appeared earlier than what we think. In this context the emergence of extraterrestrial intelligence should be not exceedingly rare (see [19], [20], [21])

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